EPA United States Environmental Protection Agency

Reduction of air pollution concentrations due to a solid barrier downwind of a roadway: wind tunnel results and dispersion model development

Dianna M. Francisco[1], David K. Heist[2], Akula Venkatram[3], Lydia H. Brouwer[4], and Steven G. Perry[2]

[1]ORAU ORISE Research Participation Program hosted at the U.S. EPA, RTP, NC, USA
[2]U.S. EPA, ORD/CEMM, RTP, NC, USA
[3]U.C. Riverside, Riverside, CA, USA
[4]Jacobs Technology Inc., RTP, NC, USA

Office of Research and Development (ORD)
Atmospheric and Environmental Systems Modeling Division (AESMD)

November 4, 2021

RLINE development to date

US-1 in Cary, NC -- Image from Google Maps

- Lots of model development for “mobile sources” over last 9 years
- R-LINE was released by EPA’s ORD as a stand-alone model
  - Numerical integration to compute concentrations from a line source
  - Dispersion curves to better fit Prairie Grass and Idaho Falls field observations
  - Depressed roadway algorithm
  - Single barrier algorithm (downwind barrier only)
- **AERMOD v19191 (2019)** added **RLINE** (*beta*) and **RLINEXT** (*alpha*) source options as part of a joint effort with EPA’s ORD, OTAQ, & OAQPS as well as FHWA
  - RLINE is a line source option (with no roadway options)
  - RLINEXT is a line source option that includes depressed roadway and barrier options
- **AERMOD v21112 (2021)** improved downwind barrier algorithm, added upwind barrier algorithm and two-barrier algorithm

Motivation:
Roadways are close to schools & neighborhoods

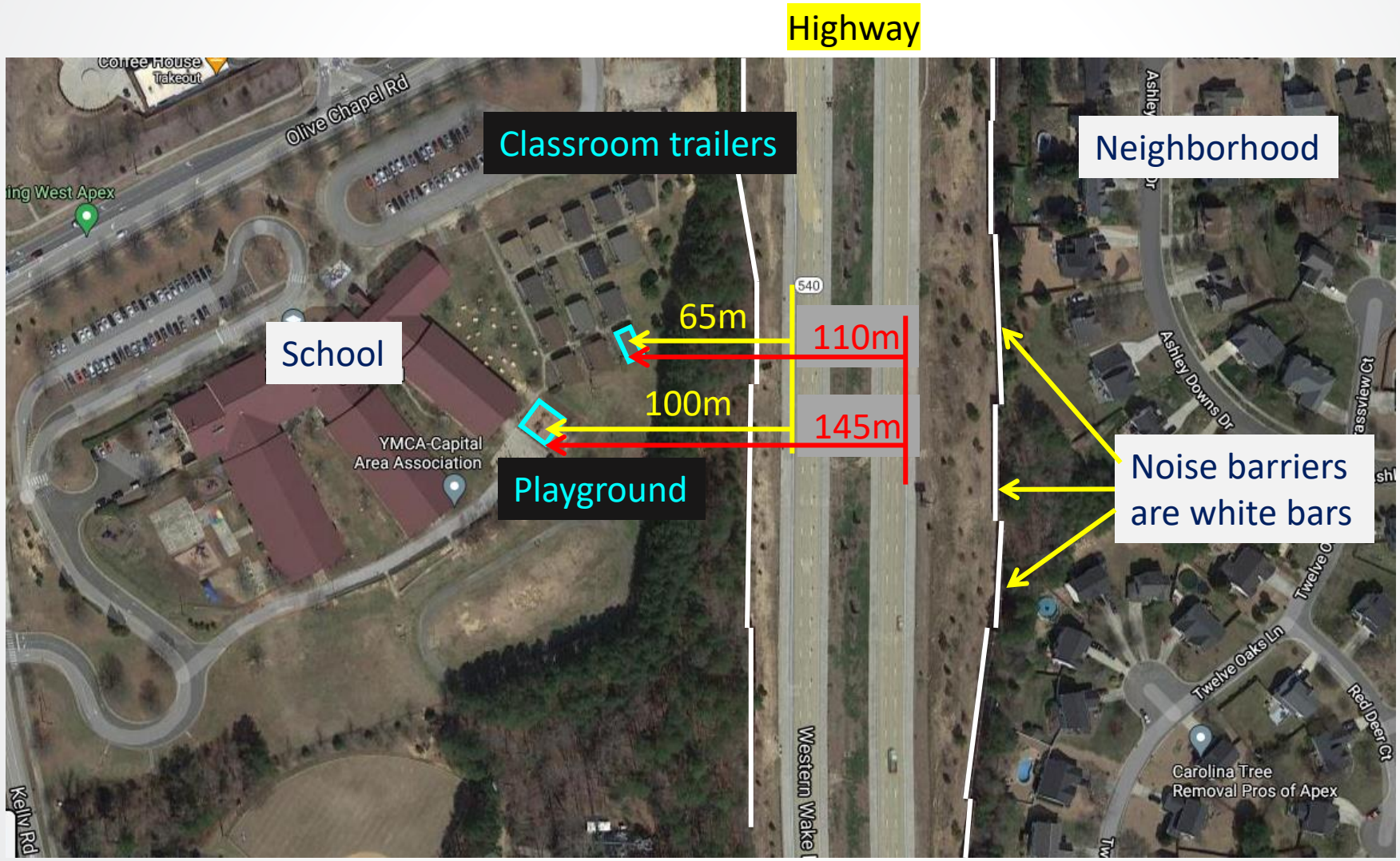


Image from Google Maps

Motivation:
Noise barriers are various heights

Barrier height about **2 m** above ground-level

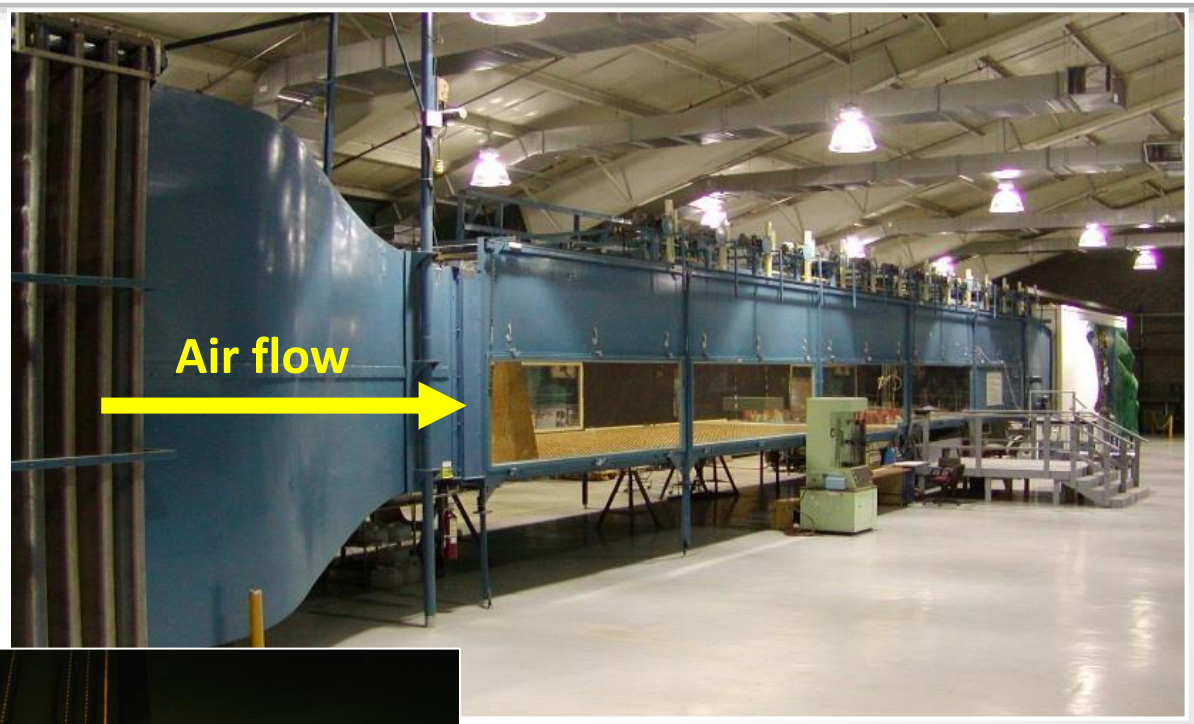
Barrier height about **4 m** above ground-level

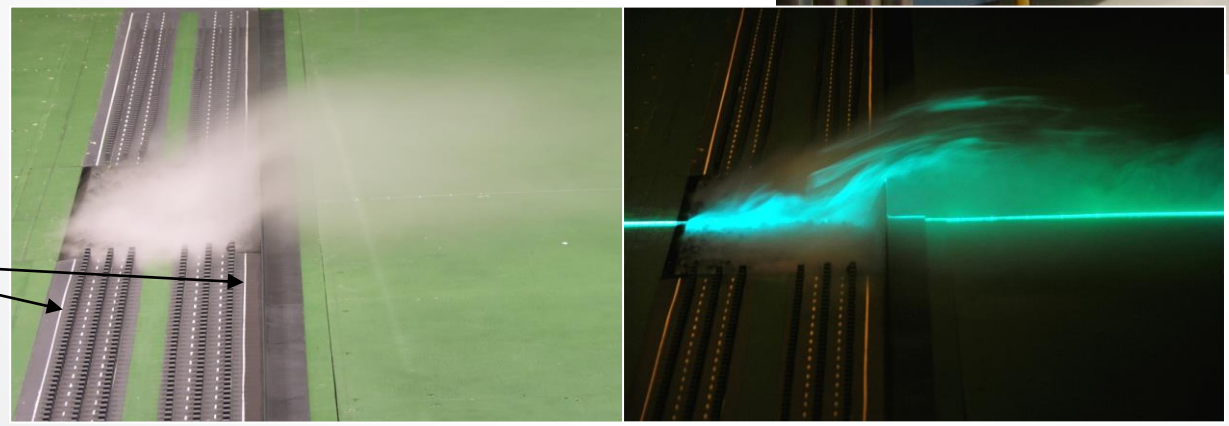
Images from Google Maps

Meteorological wind tunnel studies

EPA's Meteorological Wind Tunnel:
18.3 m long, 3.7 m wide, 2.1 m high

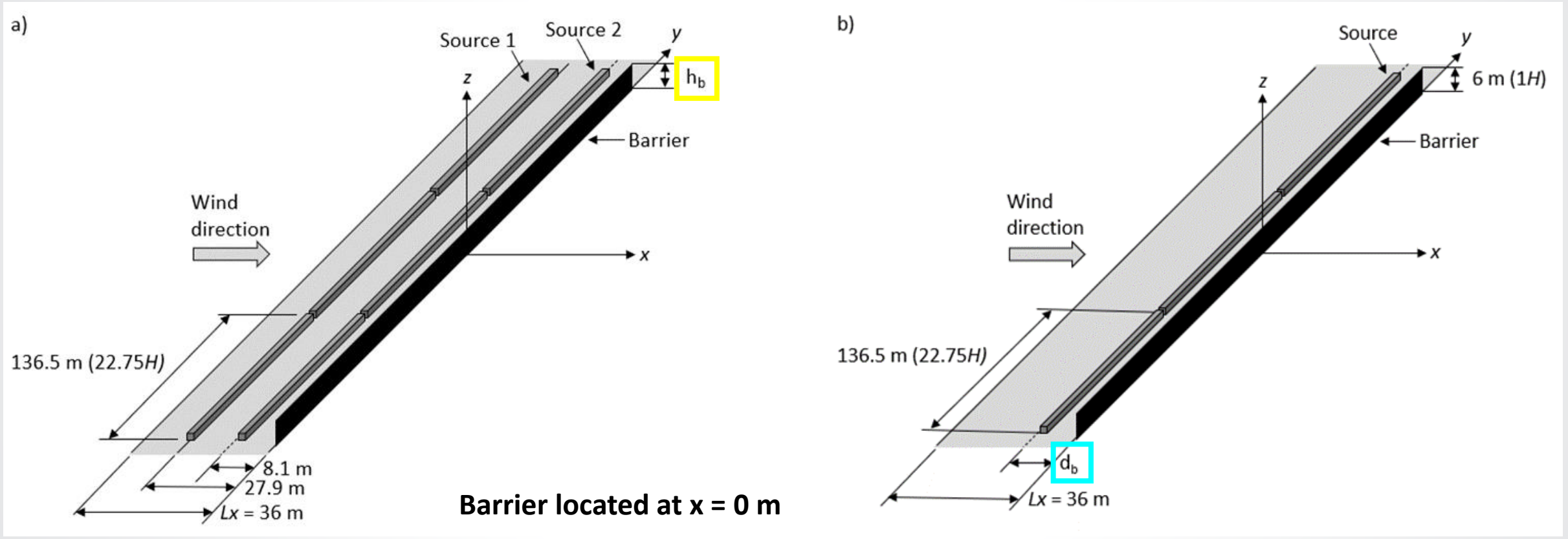
The near-road experiments:
- 1:150 scale
- Neutrally-stable suburban boundary layer
- Neutrally buoyant hydrocarbon (ethane) tracer gas emission releases





Flow visualization shown with theatrical smoke and laser sheet

Observations from wind tunnel studies: Case descriptions



Barrier located at x = 0 m

Barrier Height cases

2 line sources & downwind barrier

Testing **various barrier heights** (3, 4.5, 6, 9 m)

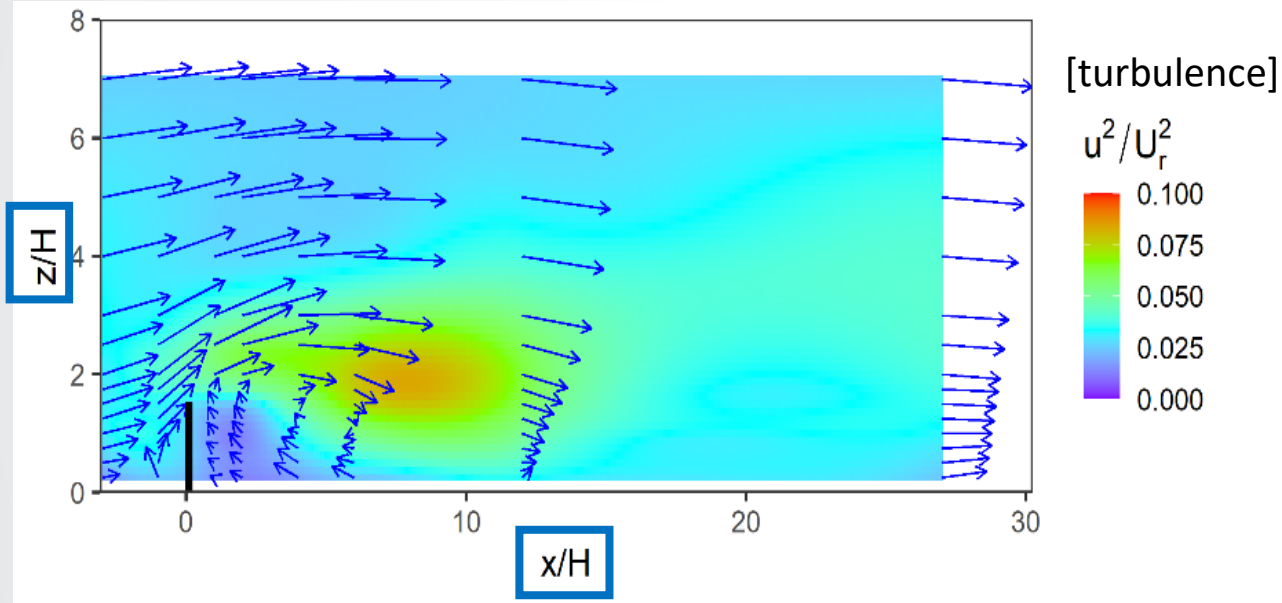
Source-to-Barrier Distance cases

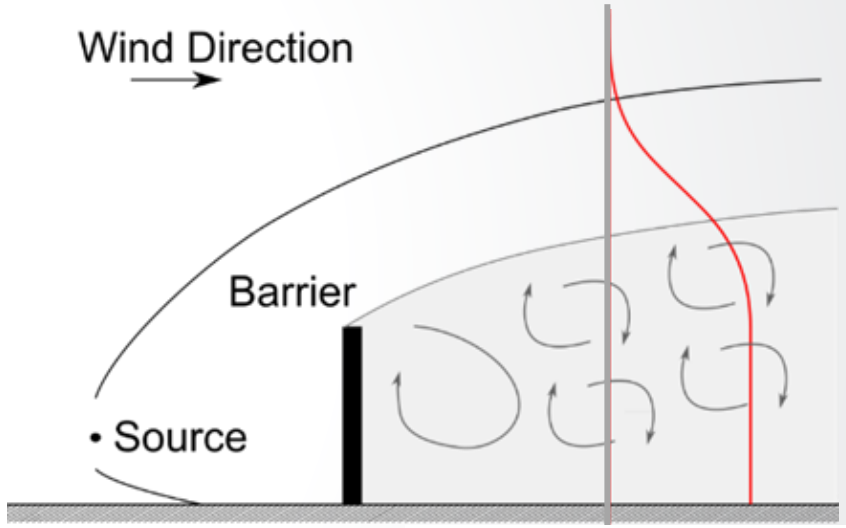
1 moveable line source & downwind barrier

Testing **various source-to-barrier distances** (6, 10, 14, 18, 22, 26, 30 m)

Observations from wind tunnel studies: Velocity & turbulence measurements

Typical velocity & turbulence patterns downwind of a barrier



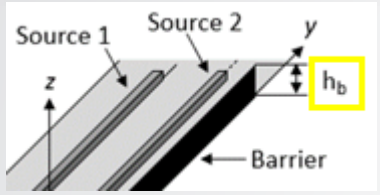


Concentration profile

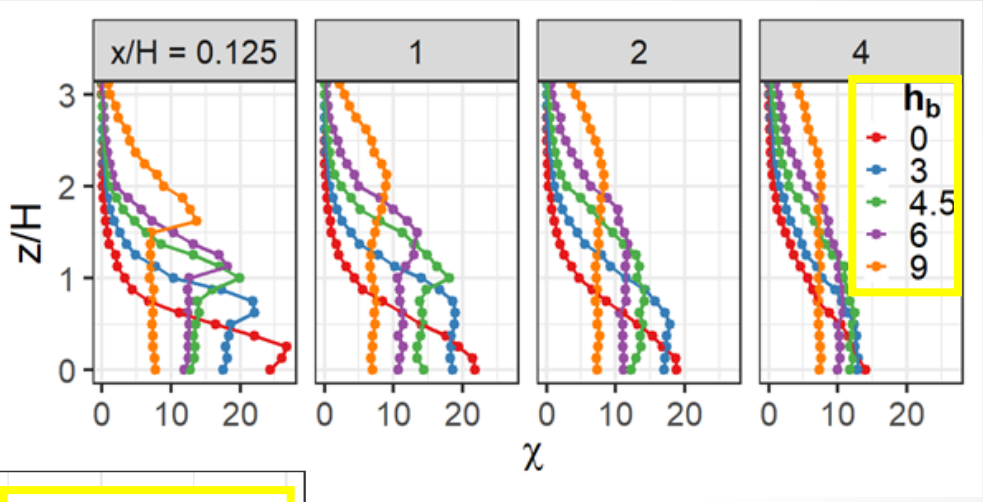
Normalized by a
"typical barrier height of 6 m"
H = 6 m

- Barrier pushes flow up and over the top of the barrier
- Increased turbulence promotes mixing
- Recirculation region downwind of barrier also enhances mixing

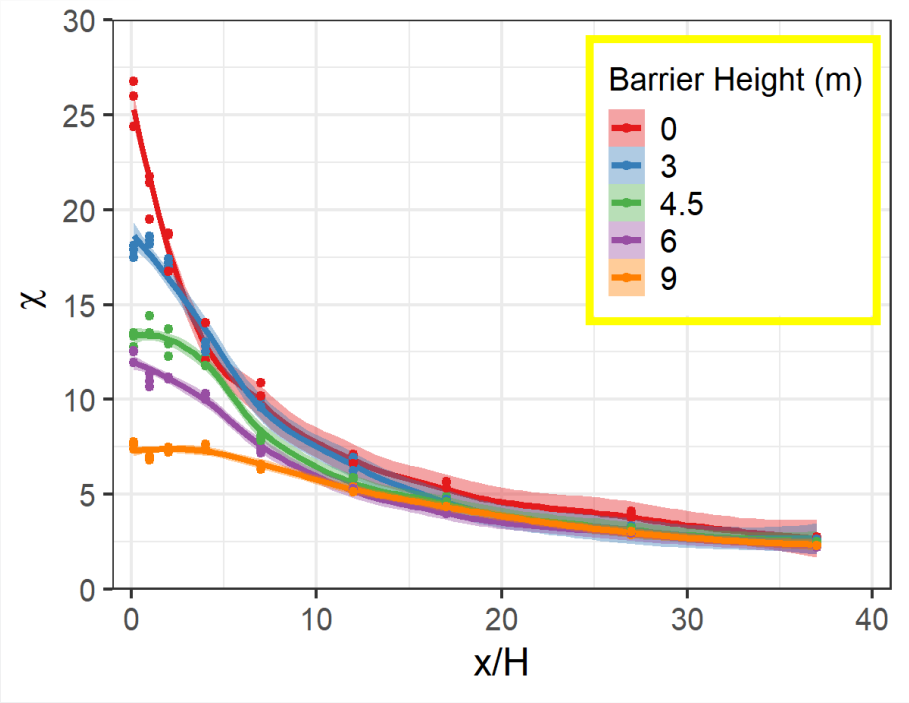
Observations from wind tunnel studies: *Barrier Height* cases



Vertical concentration profiles downwind of barrier

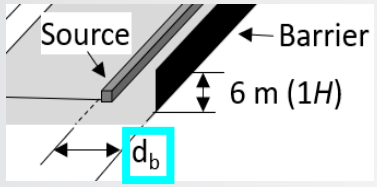


Concentrations within the breathing-level (z = 0-2 m)

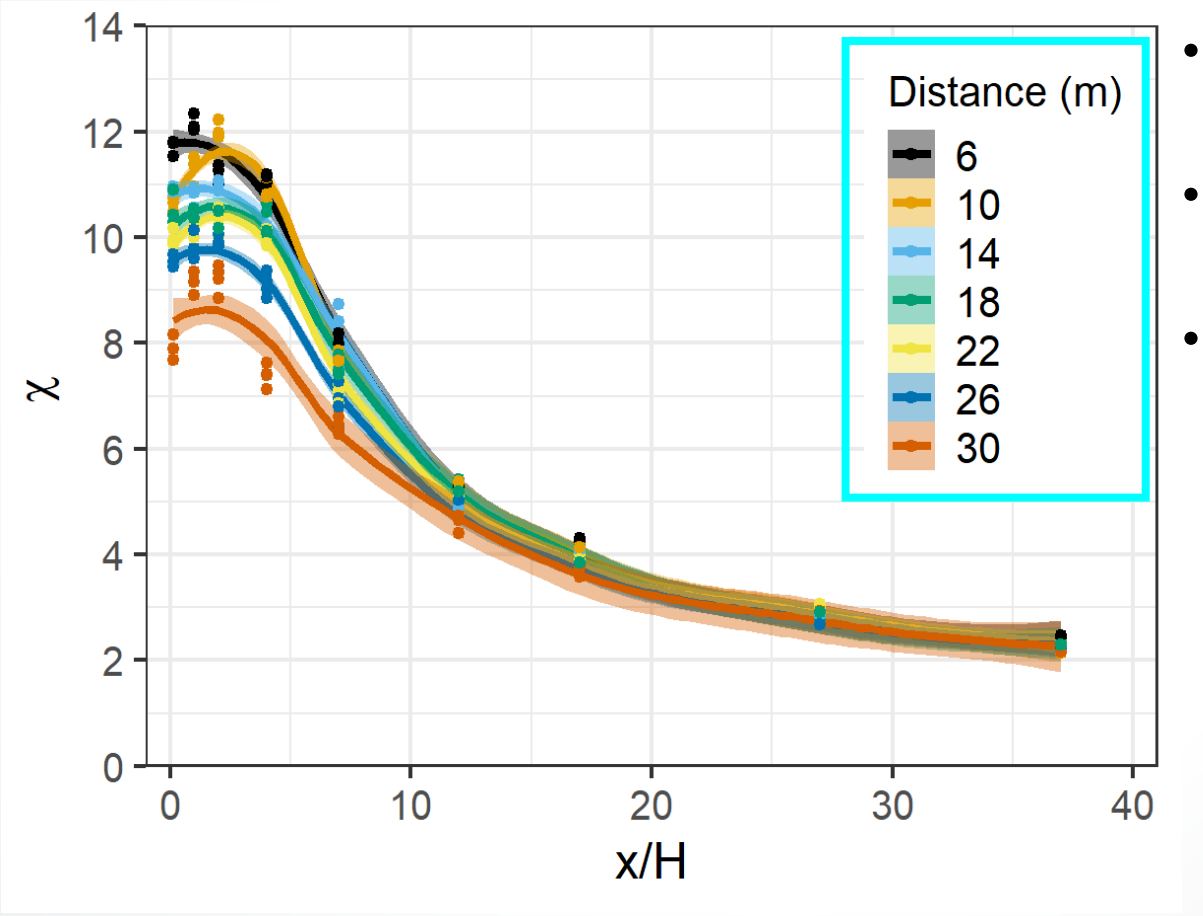


- Concentrations are **well-mixed below** $z = h_b$
- **With taller barriers**, the well-mixed region extends higher while reducing ground-level concentrations

Observations from wind tunnel studies: *Source-to-Barrier Distance* cases

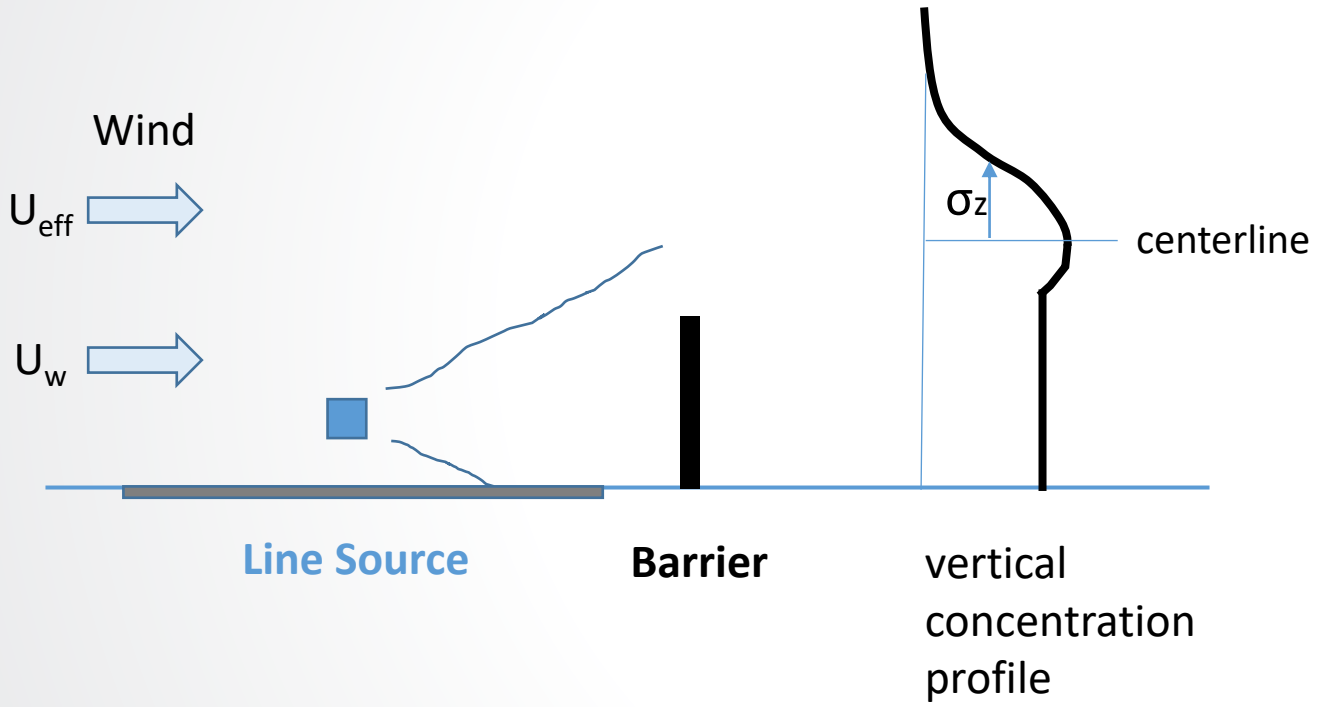


Concentrations within the breathing-level (z = 0-2 m)



- **Concentrations decreased** with increasing source-to-barrier distance
- **Less variation** in concentrations compared to *Barrier Height* cases
- **Greatest reduction** in concentrations for lanes closest to the barrier

For downwind barrier: Mixed-wake algorithm



Mixed-wake algorithm concept:

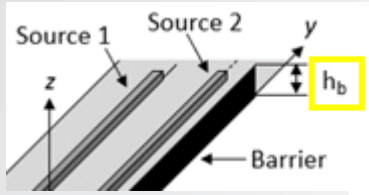
- Below the barrier, the concentration profile is flat
- Above barrier, the concentration profile retains its Gaussian shape
- The emissions are balanced between these two parts to maintain pollutant flux equal to the emission rate
- Enhanced turbulence levels downwind of barrier affect growth rate of plume

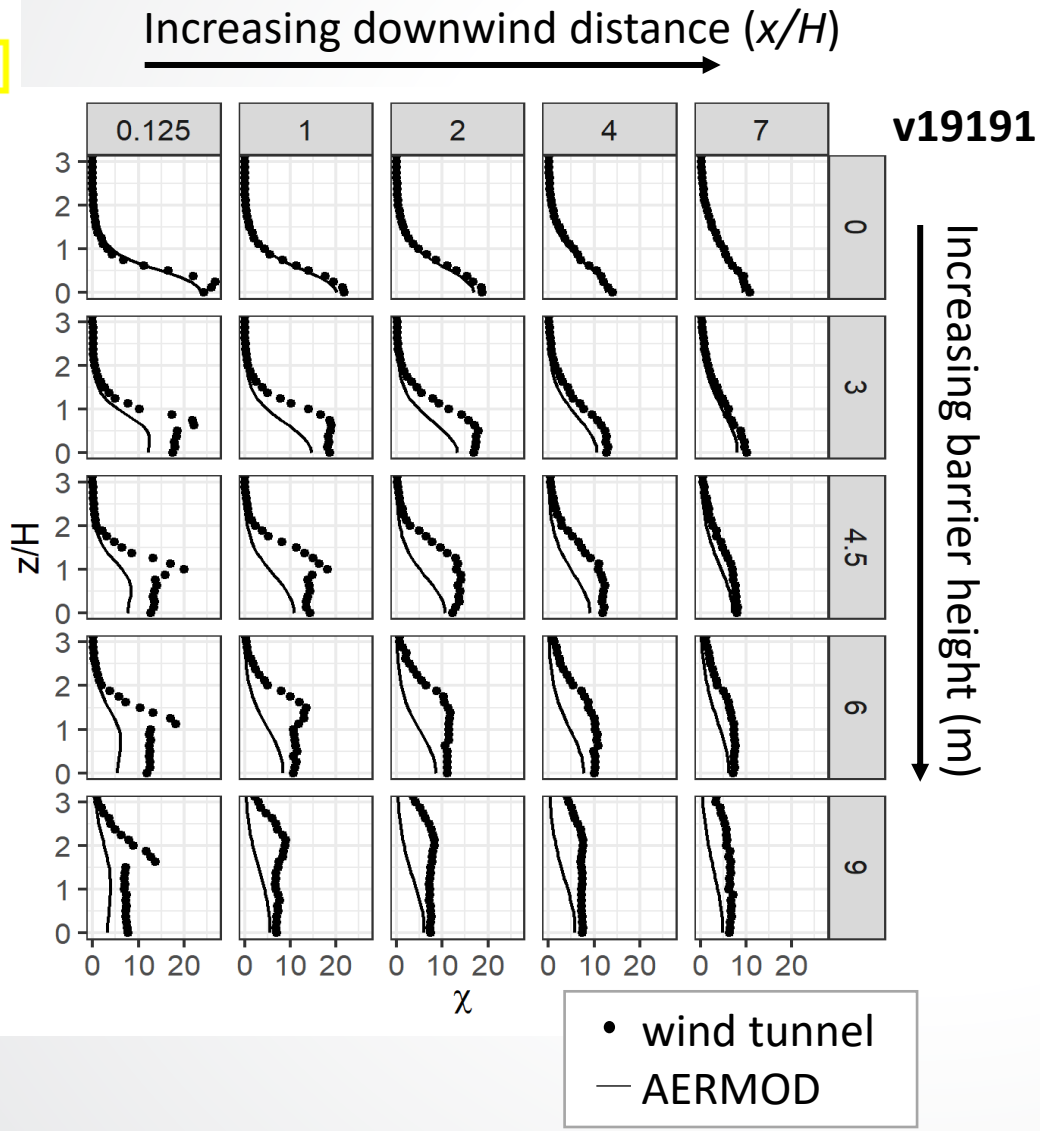
Publications:

Dispersion at the edges of near road noise barriers. A. **Venkatram**, D. Heist, S. Perry, L. Brouwer (**2021**). *Atmos. Pollut. Res.,* 12, 367–374.

Effects of solid barriers on dispersion of roadway emissions. N. **Schulte**, M. Snyder, V. Isakov, D. Heist, A. Venkatram (**2014**). *Atmos. Env.,* 97, 286-295.

Performance of downwind barrier algorithm: AERMOD v19191

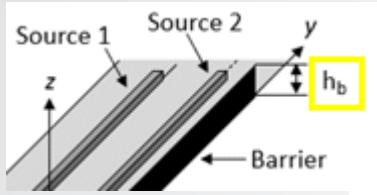


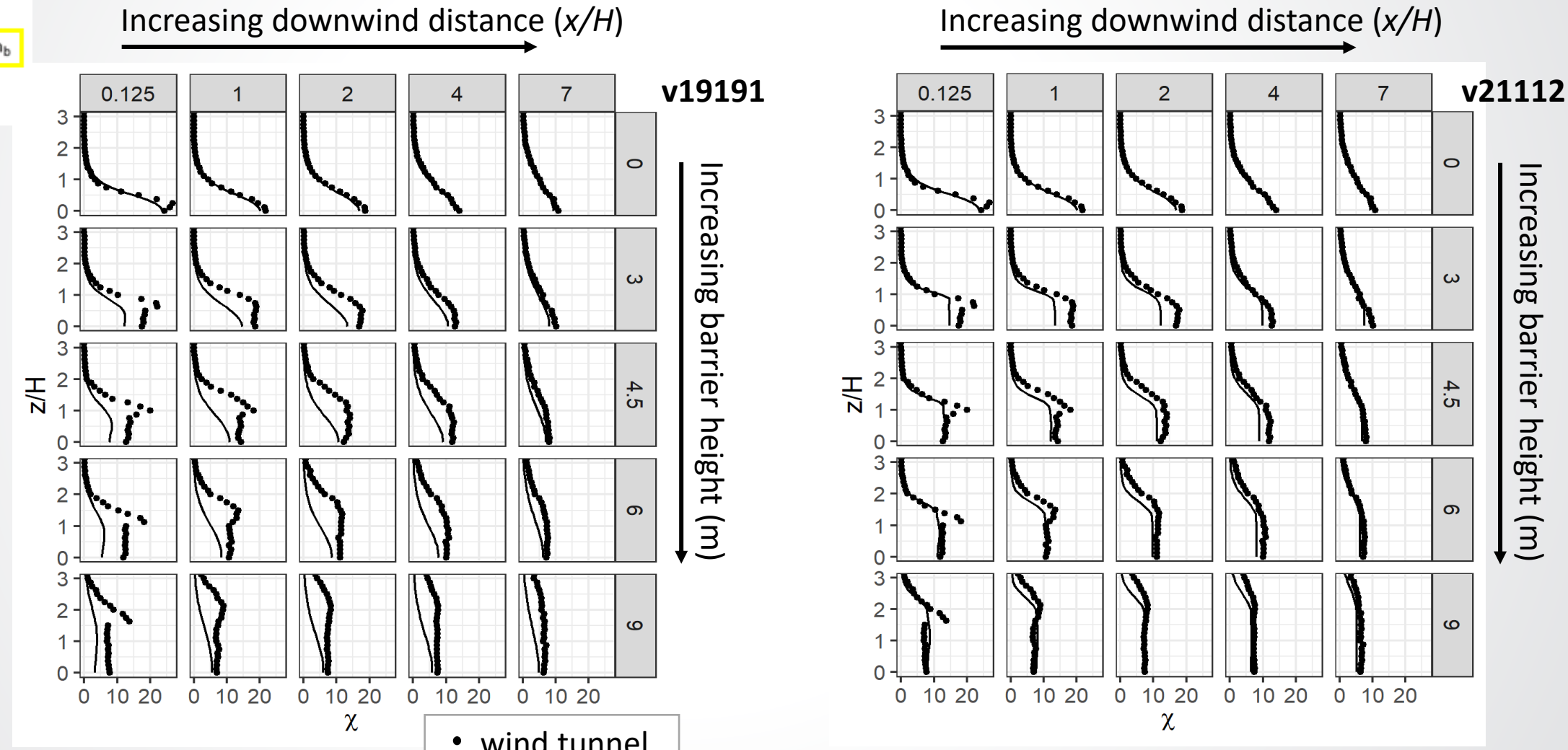


Vertical concentration profiles using barrier algorithm in **AERMOD v19191**:

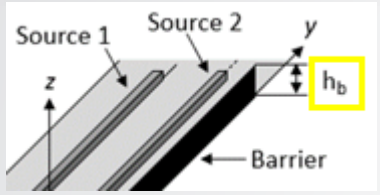
- Based on descending plume concept
- Plume lofts over barrier and gradually descends with downwind distance
- Reduces ground-level concentration with increasing barrier height
- Profile shape does not match “mixed-wake” shape

Performance of downwind barrier algorithm: Improvements with AERMOD v21112



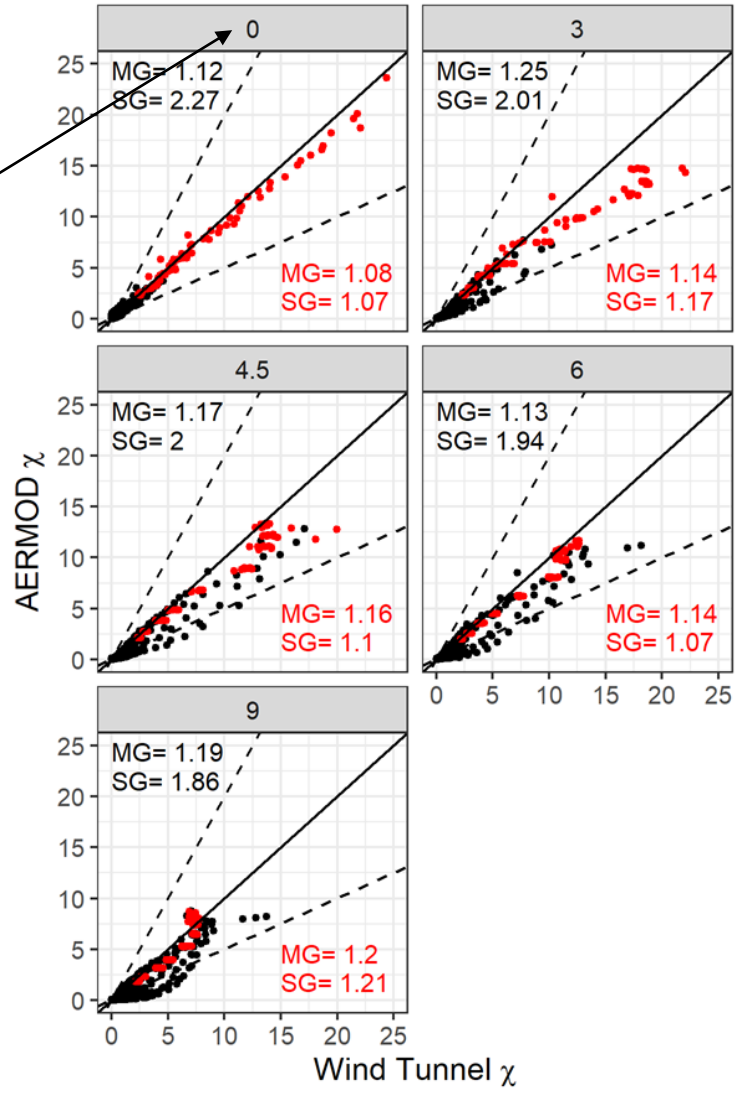


Performance of downwind barrier algorithm: Sensitivity to barrier height



Scatter plots are paired in space

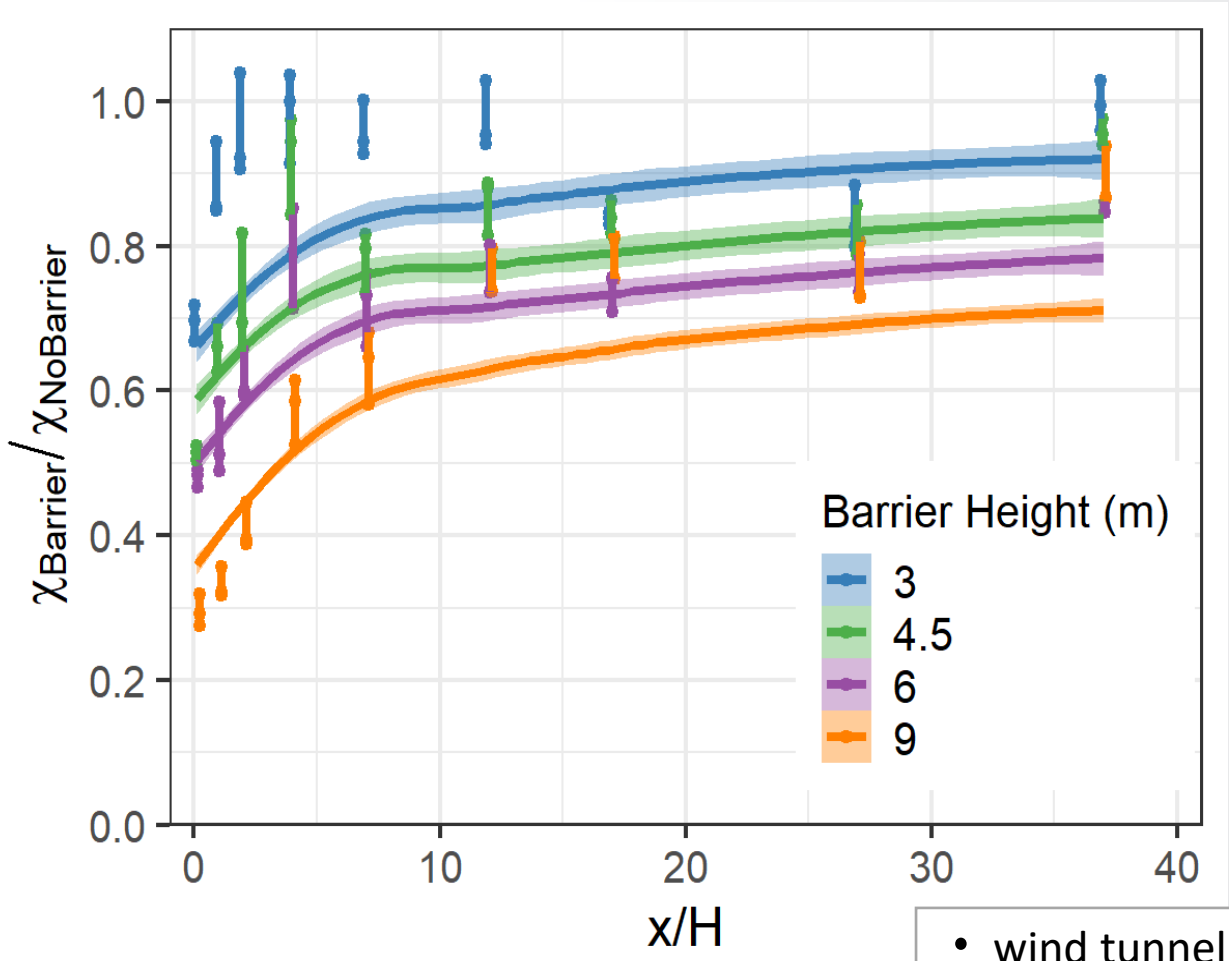
Barrier Height (m)



Black: all z

Red: $z < 6$ m

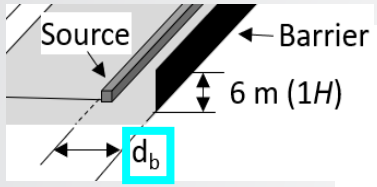
Breathing-level concentration ratios (with barrier/without barrier)



***H* = 6 m**

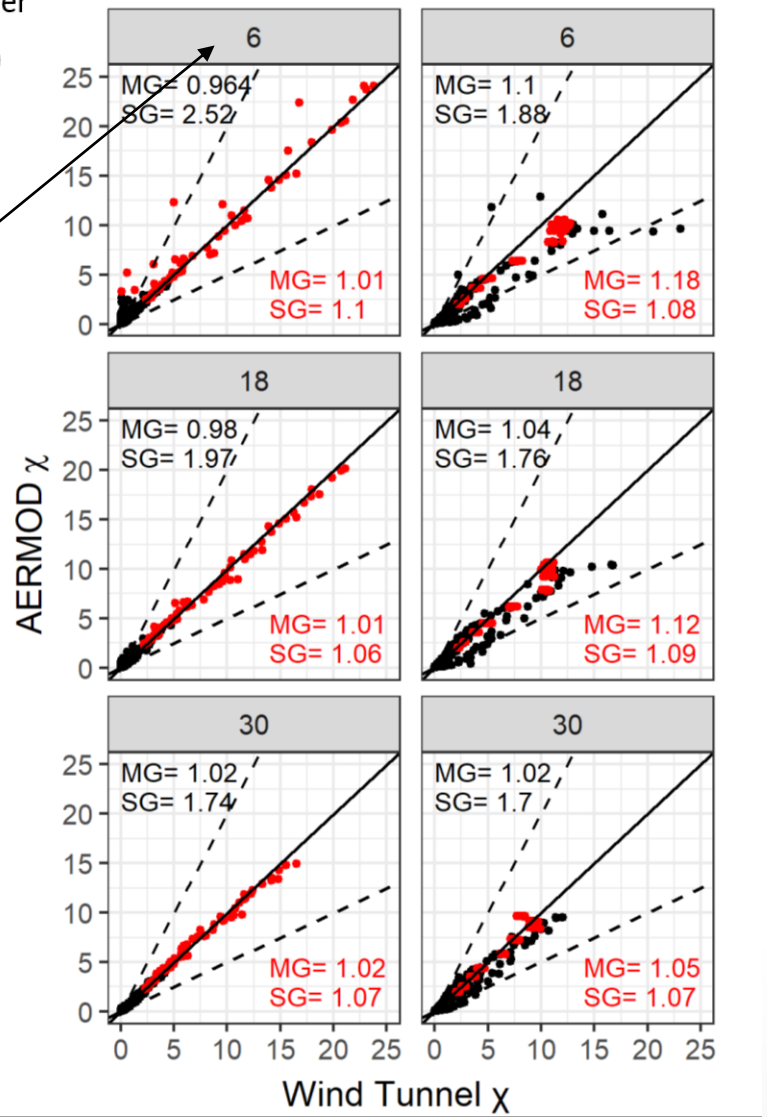
• wind tunnel
— AERMOD

Performance of downwind barrier algorithm
Sensitivity to source-to-barrier distance



Source-to-Barrier Distance (m)

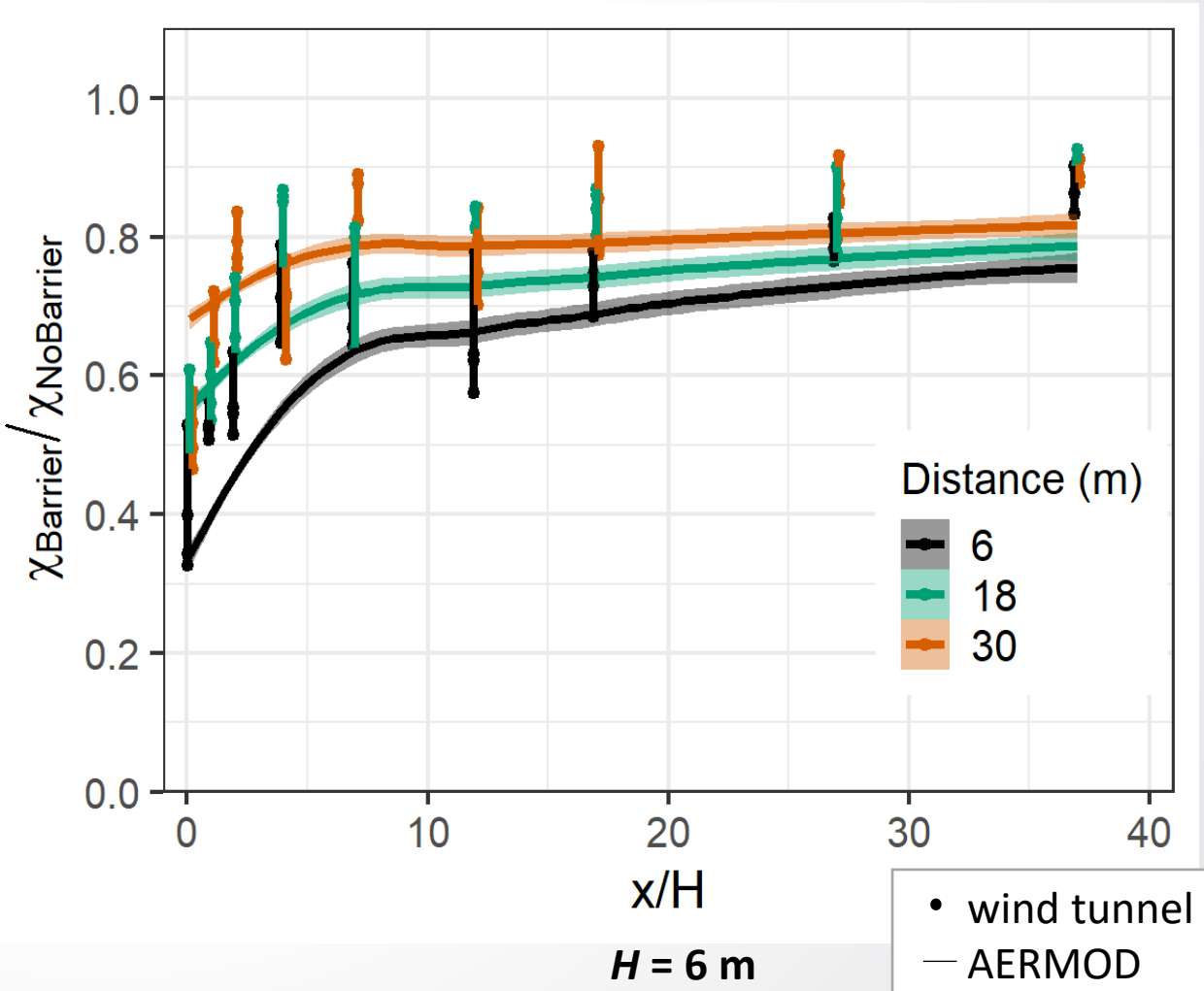
Scatter plots are paired in space



Black: all z

Red: $z < 6$ m

Breathing-level concentration ratios
(with barrier/without barrier)



Summary and future work

- **New roadside barrier algorithms were implemented in AERMOD v21112**
  - Mixed-wake algorithm for a downwind barrier
  - New algorithm for an upwind barrier (not shown today)
- **Roadside barriers can substantially reduce concentrations immediately downwind of the barrier**
- **Journal article (Francisco et al.) describing this work has been submitted to a journal**
- **Next steps include:**
  - Comparisons are planned with two upcoming field data sets (CalTrans & NCHRP)
  - Adding urban boundary layer and barrier edge effects to AERMOD's RLINE and RLINEXT

Acknowledgements

Akula Venkatram; University of California-Riverside
Steve Perry (retired), Clint Tillerson, Chris Owen, Laura Berry, Vlad Isakov, Rich Baldauf; US EPA
Michelle Snyder; John Wood Group PLC
Lydia Brouwer & Laurie Brixey; Jacobs Technology Inc.
Federal Highway Administration
Sarav Arunachalam, Alex Valencia; UNC Institute for the Environment

Contact email: francisco.dianna@epa.gov

Disclaimer: The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency. This project was supported in part by an appointment to the Research Participation Program at the ORD/CEMM, U.S. Environmental Protection Agency, administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and EPA.